Chapter 6
Construction Methods and Equipment

6-1. RCC Production Controls

The concerns regarding production of RCC can be divided into two main issues, those affecting the quality of RCC and those affecting RCC production rates. The information provided in this manual focuses primarily on determining and achieving the necessary RCC quality for a specific RCC design. However, designers are reminded that one of the primary advantages of RCC over other materials is the relative economy of the final product. This economy is a direct result of the high production rates that are possible with RCC.

a. RCC production rates. One of the cost-saving features of RCC is the rapid rate at which it can be placed and consolidated by earthmoving and compaction equipment. Generally, as with most other construction processes, the faster the placement is made, the less expensive the RCC becomes. In the case of a dam, the faster placement will mean less time between placement of lifts, resulting in lift joints with improved strength and seepage performance. Typical production rates may range from 35 to 150 m^3/hr (50 to 230 yd^3/hr) for a small RCC project, 150 to 350 m^3/hr (230 to 460 yd^3/hr) for a moderate-size RCC project, and 350 to 750 m^3/hr (460 to 1000 yd^3/hr) for a large RCC structure. At Elk Creek Dam in southwest Oregon, a maximum rate of 765 m^3/hr (1000 yd^3/hr) was achieved with an average placement rate of 450 m^3/hr (600 yd^3/hr). High production rates might not be needed or even obtainable on smaller structures where working space is limited. Regardless of the size of the project, the capacities of the batching, mixing, and transporting system must be balanced to keep pace with the placement and compaction operations.

b. System coordination. The production rate for RCC is the result of the concurrent, coordinated operation of several systems: aggregate production; material batching and mixing; RCC transportation, placing, spreading, and compacting; quality control testing; and other related operations. These related operations include bedding placement, facing system placement, gallery construction, and intake works and spillway construction. It is generally necessary to accumulate large aggregate stockpiles before starting RCC placement so that adequate stockpile reserves are available at all times during production. Adequate stockpiles are especially important if the aggregate requires additional processing or transportation from offsite sources. The potential for rapid RCC placement also provides the designer the option of limiting placement to specific time periods to take advantage of cool or warm weather to aid in controlling the temperature of the RCC. It also provides the opportunity to reduce the extent of cofferdam and diversion requirements. The designer must consider the relationship of each of these systems and balance specifications in such a way that the individual system requirements are compatible with the overall production requirements. Whenever possible, the contractor should be given the flexibility to manage the RCC production rates as long as overall schedules are met. This will allow the most economical match of material, equipment, and labor resources. However, required schedule dates must be clearly defined in the specifications, with workable controls to enforce them.

c. Segregation. Segregation is one of the most detrimental conditions that can occur in the production and placing of RCC. Handling of materials must be controlled during each phase of the operation to minimize or prevent segregation of the aggregate. Many of the preferred procedures and equipment used for RCC construction are based, in part, on favorable performance with regard to segregation.

6-2. RCC Production Plants

The RCC plant includes the aggregate stockpiles, the materials feed system, the mixer, and the discharge system. Recommended practices for each of these systems are contained in the guide specifications as well as in the references listed in Appendix A. Many of the practices recommended for conventional concrete production apply to the production of RCC. Some of the notable exceptions are discussed below.

a. Aggregate stockpiles. Segregation is the primary condition to avoid when handling aggregates. Specifications should include provisions to control operations to prevent the occurrence of segregation. Aggregates for conventional concrete are traditionally grouped into specific size groups to prevent segregation. Unlike conventional concrete, RCC aggregates are often grouped in nontraditional size ranges. This practice is intended to take advantage of the natural grading of some in situ materials in order to limit processing of the aggregate. Another intention is to minimize the number of stockpiles and, consequently, the number of handling systems. The presence of 75-µm (No. 200) fines in some fine aggregates for RCC may allow the combination of size groups without segregation. Some projects have used a single stockpile for the full aggregate grading although this is not recommended for most applications. Reducing the number of aggregate size groups and stockpiles may increase the variation in total aggregate grading and, consequently, increase the variation of properties of the RCC produced.

b. Aggregate feed system. Aggregates are usually supplied to the proportioning and mixing plant by one of three methods. The simplest method, usually employed for low-production projects, is the use of a front-end loader to charge aggregate feed bins at the plant. The loader removes aggregate directly from the stockpile and deposits the aggregate in feed bins. Standard implementation ranges from one bin for feeding a single aggregate group or two bins for feeding a fine and coarse aggregate to three bins for feeding one fine and two coarse aggregate groups. A variation of this process is to use remote feeders and conveyors to charge the plant feed bins. Again, front-end loaders haul the aggregate from the stockpile to the bin that feeds the batch plant. This is more typical of projects where the loader haul distances must be minimized. A reclaim tunnel is advantageous for large projects requiring higher volumes of aggregate. This option eliminates the use of front-end loaders by directly feeding the stockpiled aggregate into a tunnel under the stockpile and then conveying the aggregate to the batch bin.

c. Mass batch systems. Mass batching of aggregates involves transferring aggregates from the feed bin to the mass hopper. One or more aggregates are individually discharged into the hopper at prescribed accumulated target masses. Once all the aggregates are batched, they are discharged into the mixer. While mixing progresses, the mass hopper is then recharged with aggregate to continue the process. Many systems of this type have been successfully used in the production of RCC. These batch systems must be coupled to a batch-mixer. The other mixture constituents, cement, fly ash, water, and admixtures, are accumulated in individual mass hoppers or volumetric containers to be transferred with the aggregate to the mixer.

d. Continuous feed systems. Continuous feed systems are used to provide a continuous, uninterrupted flow of material and RCC. The system usually includes an initial feed bin or bins that are maintained at a certain capacity. Material is discharged from these bins through an adjustable gate opening onto a variable-speed conveyor belt. The gate opening and belt speed are varied to achieve a specific rate of aggregate feed. Belt scales, which measure the mass of a section of belt, are often an integral part of the control system where variable-speed belts are utilized. Individual aggregates are often layered onto a single belt feeding the continuous mixer. The feed rate of the other constituents is adjusted in proportion to the rate of aggregate feed. Continuous feed systems are most suited for continuous mixers, but there are a few examples of continuous-feed aggregate systems that supply a batch mixer.

e. Batch- mixers. Batch-mixers are available in several variations. The traditional mixer is a rotating drum mixer. These mixers may be stationary or mounted on a truck frame (transit mixer) and have the capacity to tilt to discharge (tilting-drum mixer). Horizontal shaft mixers, often referred to as compulsory mixers, are composed of a mixing chamber containing two horizontal rotating shafts fitted with paddles. Both mixer types have successfully mixed RCC. The drum mixer is a simpler piece of equipment. Care must be exercised not to overcharge the drum, as buildup of material on drum surfaces is a common problem. Mixing times must be carefully evaluated to ensure complete mixing of the constituents. The horizontal shaft mixers provide complete mixing in much shorter time periods; however, they are more complex equipment. The use of transit mixers should be avoided for most RCC applications. RCC is much less workable than conventional concrete and, consequently, is difficult to mix and discharge from the transit mixer. Transit mixers should only be considered for projects where the RCC volume is small, low production is tolerable, and mixtures can be properly formulated.

f. Continuous mixers. The twin-horizontal shaft mixer is the predominant continuous mixer used for production of RCC. Sometimes referred to as a pugmill, this mixer is capable of handling aggregates up to 100-mm (4-in.) NMSA; however, 35- to 75-mm (1.5- to 3-in.) NMSA is the recommended aggregate size for most applications. Continuous drum mixers, capable of mixing aggregate over 150-mm (6-in.) NMSA, are not often used for RCC construction in the United States. Continuous mixers operate best when production is uninterrupted for long periods of time. These systems are less efficient when operations require frequent stopping of the mixing process. This type of mixer is well suited for most RCC placements since continuous high production rates are desired. Control of mixtures in a continuous feed, continuous mixing process is different from batch systems. Mixture proportions are based on the feed rate of the material rather than mass per volume.

Orientation of quality assurance personnel should be required to prevent the confusion and frustration created by the differences in continuous systems compared with batch systems.

g. Mixer uniformity. Uniformity of the mixing operation is critical to good-quality RCC. Mixer uniformity testing is the primary means to establish whether consistent mixing of materials is occurring. Mixer uniformity for conventional concrete production is determined in accordance with CRD-C 55. A modified implementation of CRD-C 55 is necessary for RCC operations and for continuous mixing operations. A determination of the uniformity of cementitious materials distribution throughout the mixture is the critical component in this evaluation. Strength development is the commonly used indicator of cement content since direct cement content testing by titration methods is difficult and time consuming. Unfortunately, early age strengths of RCC are so low that using compressive strength as a uniformity indicator is not always conclusive. The probable range of production rates to be used on a project should be considered when evaluating mixer uniformity. Many continuous mixers may provide uniform mixtures at higher production rates and perform poorly at very low production rates.

6-3. RCC Transportation Systems

a. General issues. The selection of a transportation system for RCC is an integral part of the design package. The quality of the lift surface is affected by the process used to transport material to the placement area. In general, high-quality lift surfaces, particularly those requiring high lift strength, are better constructed using a transportation system that uses conveyors for transportation on the dam. Vehicle placement systems are more appropriate for placements where lift surface quality and consequent lift strength are not as critical. The apparent high relative cost of the conveyor system compared with vehicle haul systems may be tempered when consideration is given to haul road logistics, placement areas, and damage control measures. Transportation systems that combine conveyor and vehicle methods have been effective on many projects.

b. Conveyor systems. Conveyor systems have proven to be an efficient and safe way to transport RCC and conventional concrete from the mixer to the placement area. Conveyor systems can be configured in several ways. Simple installations convey RCC from the plant to the placement site with just a few fixed conveyors. A rotating, retractable conveyor then deposits the RCC on the lift surface via a drop chute. This configuration is ideal for small placements in tight quarters where the plant is located very near the placement area. The number and length of fixed conveyors increases if the plant is located some distance from the site. Some larger projects have utilized a continuous conveyor on the upstream face of the dam that side discharges RCC to a self-propelled conveyor or moveable conveyor capable of positioning a drop chute at any desired location. Segregation is minimized if the drop chute is maintained just above the top of the pile of RCC and if RCC pile heights are limited to 600 mm (24 in.). If segregation is a significant problem, RCC should be discharged onto uncompacted RCC so that it can be spread by the dozer onto the hardened lift surface. There are several basic requirements for the belt conveyors. They should be of ample width and capable of operation at speeds that meet the production requirements without mixture segregation. Depending on the speed of the belts and exposure conditions, it may be necessary to protect the RCC on the belts from excessive drying and from wetting by rain. The mechanism for cleaning the belts is a key component in conveyor operations. Many conveyors are fitted with a wiper or brush system that removes most of the mortar from the belt. Adjustment and replacement of wipers or brushes may be a frequent operation. In case of a breakdown, critical system components should be accessible for machine removal of RCC before it hardens. Drop chutes (elephant trunks) should be provided at belt discharge points to prevent segregation of material coming off the end of the belt. Also, the drop chutes must be of sufficient length and diameter to prevent plugging and at the same time prevent flaring of material that can result in unacceptable segregation.

c. Mobile conveyors. Many conveyor systems have used a system of fixed belts that feed a rotating and retracting conveyor to place RCC. These systems require the addition of more rotating/retracting units to cover large placement areas. More recent implementations have replaced the rotating/retracting unit with a mobile conveyor. One method is for the RCC supply belt to be installed over the full length of the dam. At desired locations, the RCC is diverted from the belt to a secondary belt feeding a track-mounted rotating/retracting conveyor. This mobile unit is capable of positioning a drop chute at any location on the lift surface (Figures 6-1 and 6-2). This system practically eliminates the need for vehicles to transport RCC on the dam surface.

d. Vehicle transportation systems. RCC can be hauled from the mixer or from the distribution point in end-dump trucks. Front-end loaders have been used in situations where the haul distance is short. Bottom-dump trucks and scrapers normally place RCC in full-thickness lifts and in longitudinal lanes. The distance that RCC can be hauled is dependent on road conditions, weather, traffic, and site topography. If vehicles are used for transporting from the mixer or from a

Figure 6-1. Conveyor system with self-propelled crawler-placer

Figure 6-2. Conveyor system with mobile side discharge belt

distribution point not on the dam itself, care must be taken to prevent their tracking dirt and other foreign material onto the placing site and the damage from vehicles turning on the lift surfaces.

(1) End-dump trucks. Hauling and dumping of RCC with end-dump trucks, combined with remixing and spreading of RCC by dozers, has proven to be an economical and effective method of placing RCC. While all RCC mixtures will segregate when end dumped, the tendency to segregate is more apparent for RCC mixtures with 38-mm (1.5-in.) and larger NMSA. In all cases, dozer spreading and remixing procedures should be specified and enforced to reduce or eliminate the segregation that occurs when RCC is dumped. Large front-end loaders have been used for hauling and dumping RCC to supplement dump trucks in tightly restricted areas. Modifications to the truck bed or loader bucket may be necessary to reduce segregation during dumping. Dumping RCC onto uncompacted RCC is a key method to deal with the problem of segregation. This prevents segregated coarse aggregate from accumulating on the lift surface and allows the dozer to remix the material during spreading.

(2) Scrapers and bottom-dump trucks. Scrapers and bottom-dump trucks place RCC while moving in parallel lanes. Segregation is minimal except at the margin of spread lanes where RCC is susceptible to segregation, especially with large NMSA placed in thick lifts. Also, this same area cannot be compacted until after placement of adjacent spread lanes; therefore, the time interval between placement of adjacent spread lanes will be excessive unless carefully controlled. Such delay will result in RCC that is not satisfactorily compacted and is subject to seepage. In general, RCC should never be placed in a lane pattern. A lift on a dam should be placed as an advancing face where the full upstream to downstream face advances in a uniform manner. This requirement precludes the use of scrapers and bottom-dump trucks for most dam placements.

e. Combination systems. Many projects have used a combination system where RCC is transported to the site using a conveyor and transferred on the dam by a haul vehicle. This system allows the use of inexpensive conveyors off the dam and available equipment on the dam. This practice eliminates many contamination problems; however, surface damage to the RCC by the vehicles will continue. Other configurations transport RCC from the plant with vehicles that transfer the RCC to a conveyor system for transportation onto the dam. In all cases, these systems must include a hopper between the conveyor and the vehicle. The hopper allows continuous operation of the conveyor when vehicles are not in position for loading. The hopper also prevents scattering of RCC onto the lift surface under the conveyor, which can be a major source of segregation and surface contamination.

6-4. Placement Procedures

RCC has been successfully placed in lift thicknesses ranging from a minimum of 150 mm (6 in.) (compacted thickness) to well over 1 m (3 ft), although RCC lift placements in the United States have rarely exceeded 0.6 m (2 ft). Lift thickness can vary depending on mixture proportions, plant and transport capability, placement rates, spreading and compacting procedures, whether or not a bedding layer is used, and size of placement area. For most applications, an initial lift thickness of 300 mm (12 in.) is suggested, with subsequent adjustments based on results of specified preconstruction investigations. The lift thickness should be determined by the designer and specified in the project specifications.

a. Spreading RCC. When lift thickness is limited to 300 mm (12 in.), small dozers have been successfully used to spread and level RCC. Dozer sizes range from a Cat D3 for placement rates up to 150 m^3/hr (200 yd^3/hr) to a Cat D5 size for placements up to 375 m^3/hr (500 yd^3/hr). Combinations of various sized dozers have been used to efficiently place RCC at varying placing rates. RCC should be advanced across the length of the dam for the full upstream-downstream dimension. Placing RCC in lanes must be avoided. RCC should be spread to provide a uniform surface capable of uniform compaction. Ruts, bellies, and humps in RCC surfaces should not be excessive since they prevent uniform compaction. Dozers should never operate on compacted RCC surfaces. When traversing RCC surfaces, protective sheets, such as waste conveyor belts, should be used to prevent damage to the young RCC by the dozer treads. Where lift joint quality is not critical, a single straight track of the dozer across the dam may be allowable. Most RCC contractors utilize a rotating beam laser to control the grade of the RCC lift. These units are ideal for consistent grade control whether the lift surface is level or sloping. Receivers can be mounted on dozer blades for exacting control of RCC spreading. Under production conditions it is more important to spread the RCC to a uniform surface in as short a time as possible than to spend extra time to perfect the final grade. The design of dams with lift thicknesses greater than 300 mm (12 in.) has been based on the realization that the constant spreading of the RCC with dozers not only remixes and redistributes the RCC in such a way as to eliminate (or overcome) segregation but also provides most of the required compaction. This approach also results in thoroughly distributing the paste and mortar in the mass. These procedures have been established and proven in construction and testing of large-scale, well-controlled test sections and in full-scale production of RCC for dams. Dozers spread the RCC in thin sloping layers until three to six layers create a lift with a uniform thickness of 600 mm (24 in.). After completion of spreading, vibratory steel-wheel rollers are used to compact and seal the top surface of each 600-mm (24-in.) lift. The success of this process is largely a result of the compaction resulting from the continuous tracking and natural vibration of the heavy dozers. A sloping layer method (Jiang et al. 1999; Forbes et al. 1999) has been used recently to construct lifts of multiple layes. RCC is placed in layers approximately 200 to 300 mm (8 to 12 in.) thick for a total thickness of 3 to 4 m (10 to 13 ft). With the sloping layer method, each layer is placed at an inclination of approximately 1:10 to 1:20 instead of the typical horizontal orientation. The length of the slope depends on the plant capacity and production rate with typical slope lengths of 20 to 40 m (65 to 130 ft). The sloping layer is placed for the full width of the placement and progresses the full length of the placement. The primary goal of this method is to minimize the exposure of fresh RCC until it is covered with the next sloping layer. Bedding mortar is placed on the mature RCC surface prior to placing the next lift.

b. Compaction. Each lift is compacted with a vibrating steel-wheel roller. It has been determined from various test sections and actual construction projects that RCC can be adequately compacted using a variety of vibratory compactors. These compactors range from relatively small and light asphalt rollers, used extensively for compaction of RCC in Japan, to heavy single-drum units designed to compact rock fills. However, for most applications it is recommended that a double-drum, self-propelled, midsize asphalt roller be used. Rollers of this type should have a high frequency, low amplitude, and dynamic force of 65 to 100 N/mm (350 to 550 lbf/in.) of drum width. Compaction in tight spaces inaccessible to large vibratory rollers requires the use of smaller equipment. Walk-behind rollers can be effective provided they also produce a dynamic force of at least 40 N/mm (215 lbf/in.) of drum width. Manual compaction equipment such as tampers (also known as jumping jacks) and heavy plate compactors have been effective in compacting RCC when lift thicknesses are reduced or workability levels increased. However, many other types of plate compactors and walk-behind vibratory rollers have been ineffective in compacting RCC. Performance must be verified during test section construction. Typically, four to six roller passes (a round trip with a double-drum roller across the same area constitutes two passes) are adequate to achieve desired densities for RCC lifts of 150- to 300-mm (6- to 12-in.) thickness. This result assumes compaction is done in a timely manner with appropriate equipment. It should be noted that excessive rolling can actually decrease density of some mixtures. Compaction in thick lifts after spreading in thin layers is effective provided proper dozer equipment and technique are used and the mixture is proportioned for a workability in the 10- to 30-sec range. In addition to the desired compaction, a vibratory roller provides a tight, smooth lift surface which facilitates cleanup, prevents excess water penetration in wet weather, and reduces drying of RCC in hot and arid conditions. Compaction should be accomplished as soon as possible after the RCC is spread, especially in hot weather. Typically, it is specified that compaction is to be completed within 15 min after spreading and within 45 min from the time of initial mixing for mixture temperatures between 10 and 27 °C (50 and 80 °F). Tests have shown substantial reduction in strength values if RCC is compacted later than these times or when excessive mixture temperatures occur. Cooler temperatures may allow extended time limits. While recompaction of areas damaged by traffic is possible up to the time of initial setting, this practice should be avoided because it masks areas that require lift cleanup prior to placement of the next lift.

6-5. Lift Surfaces

a. Surface moisture conditions. Following completion of rolling, lift surfaces should be moistened and kept damp at all times until the next lift is placed or until the end of the required curing period. This requirement has been one of the hardest to achieve since the tendency of the contractors has been to use water trucks or fire hoses with coarse sprays to wet the surface of the lift. Such procedures should not be permitted since good fog spray nozzles that provide an extremely fine spray are readily available. If coarse sprays are used, paste and fine aggregates sometimes erode away from the surface. Also, the operators of water trucks often make tight turns and repeated passes over the same areas in attempts to cover all parts of the surface. This procedure should not be permitted because tire action mechanically damages the surface. Even though a properly proportioned RCC mixture will not develop laitance, improper use of a water truck can produce a surface scum much like laitance because of overwetting, erosion, and tire action. Consideration should be given to requiring the use of piping and hand-operated hoses with fogging nozzles. Better yet, the RCC should be placed fast enough so that each lift surface is covered before it dries out, or it should be placed during cool and humid periods so that little additional wetting is required. However, seldom will either of these procedures completely eliminate the need for fogging the surface. Shear testing of lift joints subject to various moisture treatments indicates that some drying of the lift surface improves the bonding at the surface. Allowing an exposed surface to dry to a moisture content just below saturated-surface dry conditions is beneficial. However, further drying will decrease the bonding at the surface. Conversely, extra wet surfaces exhibit lower joint strengths than slightly dry surfaces. Such testing reinforces the use of fog nozzles to maintain moisture conditions and allows some latitude in the application of moisture during RCC operations. It may be prudent to reduce or suspend water applications 30 min to 1 hr in advance of RCC placement during hot weather. Field determinations are necessary to establish these constraints.

b. Lift surface preparation. The lift surface preparation required prior to placement of the overlying lift of RCC depends to some extent on the construction procedures and sequence being used. In all cases, the surface of the underlying RCC lift surface must be maintained in a moist condition commencing immediately following completion of rolling, and the lift surface should be cleaned, as necessary, prior to placement of the next lift. The cleanup should include the removal of all loose material, laitance, debris, standing or running water, snow, ice, oil, and grease. Dirt and debris, as well as construction traffic, should be kept off the joint surface at all times possible.

(1) Air nozzle cleanup. Under ideal conditions, cleanup is best accomplished by simply blowing the surface of the lift with an air nozzle when the RCC is less than 24 hr old.

(2) Aggressive cleanup. Surfaces that are several days old or have excessive damage, debris, or contamination may require more aggressive treatment. This can be accomplished with a combination of water hoses, brooms, shovels, buckets, and the use of vacuum trucks. A vacuum truck is a necessary piece of equipment for conditions where waste material and water cannot be easily removed from the surface.

(3) Air/water jet cleanup. If a thick laitance-like scum exists, it may be necessary to use an air/water jet for removal. Specifications should require that the contractor have this equipment onsite. High-pressure water jet cleaning will be required only in extreme cases. This procedure is usually limited to preparation of existing contaminated concrete surfaces or rock surfaces. A paragraph describing the high-pressure water jet is in the “Guide Specification for Civil Works Construction, Mass Concrete,” CEGS-03700.

c. Application of bedding mortar. A bedding mortar is a high-slump, high-cement content material that is used to increase bond between RCC lifts and to improve watertightness by filling any voids that may occur at the bottom of an RCC lift during placement and compaction. The bedding mortar must be placed in sufficient thickness to fill such voids without affecting workability of the RCC. Retarders should always be used to extend the time of setting of the bedding mortar. A typical bedding mortar contains 4.75-mm (No. 4 sieve) NMSA, is highly retarded, has a slump of 180 to 230 mm (7 to 9 in.), and contains a high quantity of cementitious materials (approximately 1000 to 1500 kg/m^3 (1685 to 2530 lb/ft^3) of portland cement and fly ash). Bedding mortar should be placed in a zone approximately 10 to 20 m (33 to 66 ft) wide in front of the area where the RCC is being spread. Application of the bedding mortar should precede placement of the RCC, usually by 10 to 15 min. The interval between spreading of the bedding mortar and placement of the RCC should be shortened during hot weather and may be extended during cool weather. Bedding mortar is usually delivered to the placement area by transit mixer for projects where vehicle access onto the lift surface is convenient, or more commonly by crane and bucket. The bedding mortar is distributed from the chutes of ready-mix trucks or from the bucket onto the lift surface and then manually spread with serrated rakes common to asphalt concrete placement. Large projects have used small four-wheel tractors with front-mounted rubber squeegees to spread bedding mortar over large areas. Bedding mortar has also been pumped onto the lift surface and applied as wet-mix shotcrete. This method is excellent for controlling the extent of bedding application and the thickness of the bedding layer.

d. Alternate bedding mixture application. Concrete has been used as a bedding mixture to provide watertightness at the upstream face of some dams. Bedding concrete is a concrete mixture having up to 19.0-mm (3/4-in.) NMSA proportioned to have a slump of 130 to 180 mm (5 to 7 in.). Bedding concrete is spread, usually by manual labor, to a thickness of 25 to 50 mm (1 to 2 in.) in a zone along the upstream face of the dam. The width of application ranges from several feet to approximately one-third of the width of the dam.

e. Adverse weather conditions. Precipitation can be a frequent occurrence during RCC construction. Generally, RCC placement and compaction at a consistent rate greater than 100 m^3/hr (130 yd^3/hr)can continue uninterrupted at precipation rates less than 5 mm/hr (0.2 in./hr). This volume of water is not usually detrimental to RCC performance. However, runoff that accumulates on the lift surface must be avoided. If the rate of precipitation increases above 5 mm/hr (0.2 in./hr), RCC operations should be suspended. The compacted RCC surface should adequately withstand effects of precipitation. Excessive rainfall may require a surface washing prior to restarting RCC placement. In general, RCC placements should be suspended when ambient temperatures drop below 0 °C (32 °F). Massive placements in protected areas may be placed at temperatures a few degrees lower so long as freezing of the surface RCC is prevented. Limits on hot weather placements depend on the temperature limits established from a thermal study and on the ability to maintain surface moisture conditions.

6-6. Placing RCC on the Foundation

Foundation treatments and dental concrete placements should be completed prior to initiating RCC placements. All large cavities, voids, surface irregularities, and areas where RCC cannot be placed and compacted should be filled with dental concrete and properly consolidated and finished. A conventional concrete foundation bedding should be used at the contact between RCC and rock at the abutments and at the dam foundation. This conventional concrete should be proportioned with an NMSA of 19 mm (3/4 in.) to provide a slump of 70 to 140 mm (2-3/4 to 5-1/2 in.) and a 28-day compressive strength in excess of the 1-year compressive strength of the RCC. The conventional concrete and the RCC should be intermixed at the abutments as described for upstream facing concrete. The thickness of the foundation bedding on the abutments should be sufficient to allow for this intermingling. The thickness of the bedding on the foundation will be governed by the roughness of the foundation but should be no thicker than is necessary to fill the voids at the RCC-foundation interface. RCC should be rolled into the concrete bedding, when possible, to ensure intimate foundation contact. Care should be taken to avoid overextending the placement of bedding concrete beyond the area to be covered with RCC. Grout-enriched RCC has also been used successfully at interfaces between RCC and rock foundations (Forbes 1999). After spreading a lift of RCC, fluid grout is poured onto the RCC surface in the vicinity of the abutment. The RCC in this zone is then consolidated with internal vibrators. The RCC adjacent to and overlapping the grout-enriched RCC is then compacted with a vibratory roller.

6-7. Facing Systems for RCC

a. Precast concrete panels. Precast concrete panels are commonly used to form vertical faces of RCC structures. Typical panels are approximately 1 by 5 m (3 by 15 ft) and 100 mm (4 in.) thick.

(1) Construction. Panels can be constructed in an offsite precast concrete facility and transported to the site, or they can be constructed onsite. Onsite construction may include a casting bed where up to 20 panels are cast at one time. This daily casting is repeated until the required number of panels have been constructed. Stack casting is a popular onsite precasting method. This method uses a casting bed where a number of panels are initially cast. A new layer of panels is then formed and cast on top of the previous panels with a bond breaker between. Membranes integrally cast with panels are easily incorporated during precasting.

(2) Placement. Placement of panels requires that a footing be constructed to level and align the first row of panels. For most applications, simple footings are all that is required. For applications where a membrane is tied to the foundation, more elaborate forming is necessary, and extensive placements must be laid up each abutment. Panels may be placed in a row fashion or a checkerboard fashion. Row placement of panels requires that panels be placed in a single row resulting in a continuous horizontal joint line. This placement method usually requires that the panels be supported by external bracing. Such bracing is secured to lower anchored panels through embedded inserts. Checkerboard placing of panels means that a row of panels is placed omitting every other panel. The next row is one-half a panel height higher than the previous row. This method allows for new rows of panels to be supported by the previous row of panels. External bracing can be eliminated using this method; however, more latitude in panel misalignment and bulging must be allowed. In all cases, panels are anchored to the RCC mass by anchor rods or straps secured to the panel by embedded inserts.

b. Simultaneous placement of RCC and conventional concrete facing or abutment coating. When cast-in-place conventional concrete is placed on the upstream face of a dam constructed of RCC, or when conventional concrete is placed against rock abutments, care must be taken to ensure that the interface between conventional concrete and RCC is thoroughly consolidated and intermixed. Consolidation should take place in a sequence such that the entire interface area is intermixed and becomes monolithic without segregation or voids in either material or at the interface itself. The recommended construction sequence is to place the conventional concrete against the rigid forms or abutment rock, then place the RCC in thin layers against the conventional concrete. Each layer of RCC should be vigorously tracked into the conventional concrete by the dozer until the full lift thickness is achieved. The two concrete types should be extended across the dam at as nearly the same placing time as can be accomplished with the equipment available. It is essential that the interface between the two mixtures be consolidated with heavy-duty internal concrete vibrators inserted at close intervals along the interface before time of initial setting occurs in either concrete mixture. Heavy-duty vibrators that are gang-mounted on a tractor, backhoe, or similar equipment should be required rather than expecting workmen with hand-operated vibrators to properly accomplish the work. Using a retarder in each type of concrete to extend the working time is beneficial in attaining a good joint between the two materials. Consolidation of this interface has at times been a difficult quality control problem. Successful consolidation requires intensive use of closely spaced heavy vibrators and care in removing segregated coarse aggregate particles.

c. Curb-forming systems. Placement of vertical, stepped, or inclined facing elements can be accomplished with a curb-forming system. This slipformed concrete placement technique is well suited for projects where the work area is large, the length of the dam is long, and the rise of the structure is limited to less than one lift per 24-hr period. Concrete is generally supplied to the slipform machine by transit mixer; however, a concrete pump with extended boom could be used where access onto the lift surface is difficult. This method can result in good-quality facing elements constructed with minimal interference to ongoing RCC operations. This method requires that elements gain sufficient strength to support RCC placement within 24 hr. The resulting high-strength mixtures may result in extensive cracking within the elements if proper controls are not implemented.

d. Forming systems. Many projects have used traditional forming systems to form the vertical, stepped, and sloped faces of RCC. These systems are used as forms for a conventional concrete facing or for RCC placement directly against the forms. Standard formwork for constructing vertical faces is common. External bracing is used to support forms that are “jumped” to the next level as the dam rises. Stepped form systems are often supported by internal and external bracing secured to the top surface of the previous step. Specifications must include a requirement to ensure that the top surface of stepped forms are at the required elevation. Sloped face forms are similar to forms for vertical faces. Some variations use embedded wire anchors secured to the previous lift surface. Anchors are often short lengths of reinforcing steel driven into the RCC surface. In any case, the formwork must be capable of withstanding the forces created by significant internal vibration of conventional concrete or surface compaction of RCC. The impacts of forming operations on RCC placement increase as the width of the dam section narrows and the length of the dam increases.

6-8. Installing Joints, Waterstops, and Drains

a. Transverse contraction joints. Placing vertical transverse contraction joints in dams constructed with RCC and installing waterstops in these joints near the upstream face should be considered for crack control. This technique and its many variations have been successfully used in many dams. Not all transverse joints require the installation of waterstops and joint drains. One common and effective construction procedure involves forcing galvanized sheet metal panels into the uncompacted RCC lift surface with a backhoe-mounted vibratory blade (Figure 6-3) to form a line of sheet metal in the lift extending from upstream to downstream. Since the metal panels are aligned with those in each lower lift, they form a vertical separation plane from top to bottom. The number and placement of these contraction joints should be determined by a thermal study, construction considerations, and examination of the foundation profile parallel to the dam axis. Another construction procedure involves placement of a sheet panel wrapped with PVC sheeting at the intended joint location. After RCC is carefully placed on each side, the steel panel is removed, leaving the PVC sheeting at the desired joint location. The RCC is then compacted. Generally, this method is effective only when using a crawler-placer, and even then requires great care by workers for proper installation (Figure 6-4).

b. Waterstops and joint drains. The installation of waterstops and downstream joint drains typically requires the placement of conventional concrete. This is usually done in conjunction with placement of a conventional concrete upstream facing. A common method is to fabricate an assembly that includes a steel plate, to form a portion of the joint, coupled to a vertical pipe that forms the round joint drain, and a framework to support the waterstop. In the area of the waterstop and joint drain installation, the facing concrete extends downstream to encapsulate the entire unit (Figure 6-5). Grout-enriched RCC appears to be an effective alternative to conventional concrete for encapsulating waterstops and joint drains (Forbes 1999). Waterstops and joint drains are not usually included in structures with an impermeable membrane at the upstream face or in structures that do not impound a permanent reservoir.

c. Face drains. Many projects incorporate a form of face drain in the design of the structure. As in conventional concrete structures, face drains in RCC structures intercept water seeping along lift joints, random cracks, and construction joints and transfer that water via a drainage system to some downstream discharge point. Several methods have been used to provide these drains. A popular method is to drill a pattern of vertical or angled holes from the top of the dam down to intercept the gallery or drainage manifold. Another method is to install horizontal drains on the lift surfaces. These drains can be permeable pipes along lifts or rock drains within lifts.

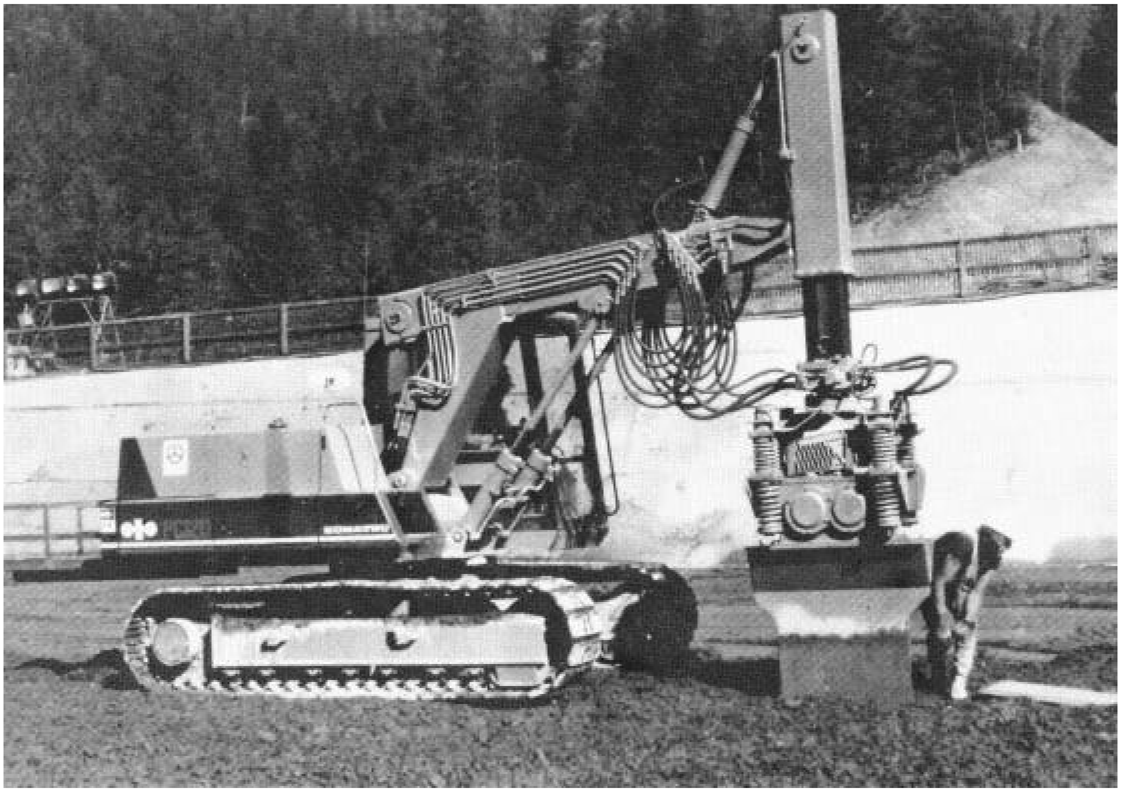

Figure 6-3. Installation of sheet metal joints with vibrating blade

Figure 6-4. Transverse contraction joint construction with plastic-wrapped joint form

Figure 6-5. Installation of waterstop, joint drain, and crack initiator